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EVOLUTION OF THE USES OF GORSE IN NATIVE AND INVADED REGIONS: WHAT ARE THE IMPACTS ON ITS DYNAMICS AND MANAGEMENT?

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RÉSUMÉ.— *Évolution des usages de l'ajonc dans ses régions d'origine ou envahies : quels impacts sur sa dynamique et sa gestion ?*— L'introduction et l'expansion géographique des espèces invasives, comme leur régression, suivent souvent des processus où le rôle de l'Homme est central. C'est le cas de l'Ajonc d'Europe (*Ulex europaeus*) qui a été introduit volontairement dans plus de 30 pays différents, et est considéré comme l'une des *« 100 of the world's worst invasive species »* par l'UICN. Dans sa zone d'origine (principalement Grande-Bretagne, Bretagne, et Galice), il n'est pas perçu comme problématique car il fait l'objet d'une gestion régulière et efficace. L'ajonc y a longtemps servi d'auxiliaire agricole, fournissant notamment du fourrage, et les pratiques de gestion se sont développées parallèlement à ces usages. Cependant, la plupart de ces pratiques et usages n'ont pas été transposés dans les zones introduites. Notre étude a pour but de décrire l'évolution des usages et pratiques de gestion traditionnels et contemporains des ajoncs dans les zones d'origine comme dans les zones envahies, afin d'une part de retracer l'histoire et les motivations de son introduction de par le monde, d'autre part de proposer des pratiques de gestion novatrices et durables. Pour cela, nous avons été amenés à reparcourir les représentations et usages de la plante en zones d'origine comme en zones envahies. Les données historiques et contemporaines ont été recueillies par des recherches bibliographiques et documentaires. Nous avons également effectué un focus sur une zone d'origine (la Bretagne), et une zone envahie (l'île de La Réunion), à l'aide d'enquêtes par entretiens. Nous avons ainsi pu retracer le panorama des usages agricoles des ajoncs, les motivations de son introduction dans l'empire colonial européen, la perte progressive de ces usages, et les techniques contemporaines de contrôle. Nous avons également montré que les usages traditionnels de la plante et ses vertus demeurent connus dans la zone d'origine : les agriculteurs témoignent d'un intérêt pour tenter de recycler ses qualités fourragères, et les partenaires institutionnels et industriels pour en faire une ressource commercialisable (combustible, fourrage, fertilisant). On observe également des essais pour des innovations de gestion, dans les espaces naturels, comme dans les espaces agricoles. Ces travaux suggèrent des innovations possibles, ainsi que leurs limites, pour les zones envahies.

SUMMARY.— The introduction and geographic expansion of invasive species, as well as their possible decline, often follow processes in which humans play a central role. This is the case for gorse (*Ulex europaeus*), which was intentionally introduced into more than 30 countries and is considered as one of the *"100 of the world's worst invasive species"* by the IUCN. Within its native range (Western Europe), it is very widespread in Great Britain, Brittany and Galicia, but it is not seen as a problem there as it is routinely and effectively managed. Gorse has long been used for agricultural purposes, and management practices have been developed in parallel to these uses. However, these practices and uses have not always been transferred to the introduced regions. The aim of our study was to investigate the changes in the use of gorse, as well as the traditional and contemporary management practices in its native and invaded ranges; partly to trace the history and motivations behind its introduction around the world, and partly to propose innovative and sustainable management practices. We retraced the history of the uses and perceptions of this plant in its native and invaded ranges by focusing on one native region (Brittany) and one invaded region (Reunion Island). Historical and contemporary data were collected using bibliographic and document searches as well as survey interviews. Thus, we were able to retrace the wide range of agricultural uses of gorse, the motivations behind its introduction into the European colonial empire, the gradual decline of these uses, and modern control techniques. We also show that the traditional uses of the plant and its virtues are still well-known in the native range: farmers are showing an interest in reemploying it for its fodder qualities, and institutional and industrial partners are interested in making use of it as a marketable resource (fuel, fodder and fertilizer). We also looked at tests for innovative management tools, in both natural and agricultural regions. These works suggest possible innovations, but also their limitations, for the invaded regions.

Invasive alien species are often regarded as a major cause of biodiversity loss, and a disturbance for human activities; their management can result in high economic costs (Mack *et al.*, 2000). Yet generally, they pose little or no problem in their native range, and only acquire an invasive status in the introduced regions. This status is justified by their capacity for geographic expansion, their ability to outcompete local species, and their actual or potential negative impacts (Mack *et al.*, 2000). Many animal and plant species that are now considered as invasive were originally introduced intentionally, either for economic purposes (most often for agriculture or forestry), aesthetics, or for cultural reasons such as nostalgia, traditional medicine or religion (Binggeli, 2001). The introduction of a species is therefore initially associated with a positive perception, which is often related to these uses.

There are several possible reasons for the change in status observed in the introduced regions. Firstly, their ecological and climatic conditions may be particularly suitable for the introduced species, or natural enemies (predators, parasites, pathogens) that limit its spread in its native range may be lacking (Keane & Crawley, 2002). Secondly, the biological characteristics of the species may evolve in the introduced region towards increased competitive ability, better reproduction, or faster growth, as demonstrated in many cases, particularly for plants (reviewed in Müller-Schärer & Steinger, 2004; Bossdorf *et al.*, 2005). Thirdly, agricultural and forestry practices, or the type and frequency of the disturbances, may differ from those in the native range and encourage the spread of the species (Mack, 2001). In addition to these biological factors, the species might be perceived differently, given its exotic origin. In the global perspective for biodiversity conservation which has emerged since the 1980s, the stakeholders involved in nature protection give priority to native and endemic species. However, these perceptions are highly variable depending on the social group, and it is not at all unusual to find that an alien species considered as invasive by ecologists and managers, is highly valued by the local population (Dalla Bernardina, 2010). If an invasive species does not pose any problem and/or is under control in its native region, this could be due to biological reasons, because its expansion dynamics is lower, and to societal reasons, because its presence is accepted and its management benefits from many years of practice. It is these aspects that we studied for gorse, *Ulex europaeus*, a shrub that is native to Europe, which was intentionally introduced into every continent for agricultural purposes (Holm *et al.*, 1997) and was later considered to be among the "*100 of the world's worst invasive species*" by the International Union for Conservation of Nature (Lowe *et al.*, 2000).

Many studies have identified the biological and ecological factors that help to explain the invasive success of gorse, such as the ability to grow in poor soils, high growth rate, seed production and seed longevity, a wide climatic niche, and a large evolutionary potential (Hill *et al.*, 1996; Atlan *et al.*, 2010; Hornoy, 2012; Hornoy *et al.*, 2011, 2013). The expansion of gorse has negative socio-economic impacts, particularly on agricultural land. In addition, it can form dense thickets that restrict movement and limit the development of other species. Lastly, it is a pyrophilous species that encourages the spread of fires. Gorse was introduced outside Europe mainly in the 19th century, into several countries colonized by Europeans, such as Reunion Island, New Zealand, Australia, the United States, Hawaii, and Chile (Hornoy, 2012), where it is currently considered as a major invasive species and a noxious weed (Holm *et al.*, 1997; Lowe *et al.*, 2000). The current management of gorse involves physical, chemical and/or biological control. These methods are often expensive and not always effective (Hill *et al.*, 2008), in contrast to the situation in the native regions. Therefore, it is likely that economic, social and technical developments play an important role in gorse invasiveness as well as the difficulty in controlling it.

By listing the management methods and perception of the plant over time, researching whether knowledge and traditional practices were introduced at the same time as the plant, and if not, analysing why, it may be possible to gain a better understanding of the introduction and expansion dynamics of gorse, and thus find innovative and sustainable management practices. To this end, we focused on one native region, Brittany (Western France), and one invaded region,

Reunion Island (Indian Ocean), for which we carried out documentary research, a bibliographic search, and survey interviews. We broadened this study to other native and invasive regions, using digitized documentary sources.

First, we describe the traditional uses of the plant in its native range, as well as the management and control methods that were linked to these uses at the time when gorse was exported to the colonies, by studying the case of Brittany (Western France) in particular. Then, we present the main uses that motivated the introduction of gorse in Reunion Island (Indian Ocean), and explore the extent to which these motivations are found in other colonies. We then study the actual uses of gorse in the introduced regions, and the problems encountered in managing and monitoring its geographical expansion. This leads us to question the transfer of traditional practices and knowledge from native to introduced ranges. Lastly, we describe the historical developments in Breton agriculture, the abandonment of traditional uses and the development of modern control techniques. This study has encouraged us to take a fresh look at innovative management methods. We conclude with the lessons that can be learnt, cautiously, for a more global perspective.

MATERIALS AND METHODS

GORSE

Ulex europaeus, the common gorse, also named furze but hereafter referred to as "gorse", is a perennial, evergreen thorny shrub (Fig. 1). It is a nitrogen-fixing Fabaceae and is very high in protein. This pioneer species mainly occupies open environments on acidic soils. It reaches its adult height of 1 to 4 metres between the ages of 5 and 7 years. It is also a pyrophilous species: its presence contributes to fires because it is highly flammable, and seed germination is triggered by fire. Its flowering period lasts for a very long time (2 to 10 months) and one single plant can produce tens of thousands of seeds per year, and these seeds can remain viable for more than 20 years (Hill *et al.*, 2001).

Figure 1.— Gorse (*Ulex europaeus*): a very thorny shrub (photo Atlan, 2008).

BRITTANY

Brittany is a region located in western France, with a low lying topography (altitudes up to 380 metres), and a strong maritime influence. Until the 1960s, the inland region was essentially agricultural, and fairly poor. Gorse is very common there, and is primarily found in open environments, such as heathlands, abandoned land, and along the edges of fields and forests. Brittany is essentially a maritime area where fishing and deep sea navigation have been and are still traditional practices, and many settlers and immigrants have moved from this region to French overseas territories, including Reunion Island (Bourde de la Rogerie, 1998).

The data collected about Brittany were obtained from literature searches and two surveys based on about 30 semi-structured interviews with people involved in the management, history, or improvement of natural or agricultural Breton areas. The first survey was carried out in 2004, and its goal was to determine traditional and contemporary uses and management methods. The second was carried out in 2010 and its goal was to add to the information on traditional uses and practices, and to research present or potential management innovations.

REUNION ISLAND

Reunion Island is one of the French overseas departments. It is a small tropical island, located in the Indian Ocean, with altitudes up to 3000 m. The island was uninhabited before it was settled by the French in 1665. Agriculture was first developed on the coastal ring, and then at medium altitudes. The higher altitudes of the island are areas with little anthropogenic impact, and the flora there is predominantly comprised of indigenous and endemic species (Strasberg *et al.*, 2005). Gorse is found between 1,000 and 2,500 metres in cultivated high plains as well as protected natural environments, where it is considered a major invasive species and a threat to native biodiversity (Triolo, 2005).

The data collected about Reunion Is. were obtained from literature searches (books on geography, botany, agronomy, agriculture, engineering and land-use planning, maritime and colonial records) and local archives (departmental archives, bishopric archives, and Reunion Rural Development Association archives). These data were supplemented with a survey based on semi-structured interviews (carried out in 2013/2014) with 40 people (agricultural stakeholders, residents and users of regions with gorse, and managers or experts of natural sites).

OTHER NATIVE AND INVADED REGIONS

Other native regions of gorse include the European Atlantic coast, particularly countries that formed colonies: United Kingdom, Spain and Portugal. Gorse was introduced into every continent. It is found at sea level in cold or temperate latitudes, between 1000 and 2500 metres in the tropics, and between 2000 and 3500 metres near the equator. The data collected in these areas are literature-based: scientific articles and books, reports and digitized archives. The available data on the uses of gorse in the invaded range vary from country to country. A lot of data can be found in New Zealand and Australia, where the control of gorse has been ongoing for a long time; data are more fragmented in North and South America and on oceanic islands. Documents that can be used to at least determine the introduction dates have also been found for many other regions.

For non-English citations, the book excerpts and the verbatim were translated into English by the authors.

RESULTS AND DISCUSSION

USES AND MANAGEMENT OF GORSE IN ITS NATIVE REGIONS

In Europe, the ties between gorse and human activities are very old and date back to the Neolithic period. In fact, the species *Ulex europaeus* (and the genus *Ulex*) originated from the Iberian Peninsula, and it probably colonised north-western Europe during Neolithic times, when the ice was melting (van Zeist, 1964; Hornoy *et al.*, 2013). The development of agriculture indirectly helped this process, because man opened up the environment by clearing the forests (Webb, 1998). Gorse has been used in Western Europe for a long time, at least since the 12th century (e.g. Chevalier, 1941 for France; Lucas, 1960 for Ireland).

THE MAIN TRADITIONAL USES OF GORSE IN EUROPE.

Gorse was widely used for agricultural purposes in western France (primarily in Brittany), in the north-western part of the Iberian Peninsula (Galicia, and the Basque Country) and in the British Isles. It was used in several ways: as a quickset hedge, fencing, fodder, fuel, fertilizer, animal bedding, a soil stabilizer, building material for mud houses and roofs, a source of dye, for chimney sweeping and folk medicine (Lucas, 1960; Beaulieu & Pouëdras 2014). The use and

cultivation of gorse are mentioned in many publications from the 18th and 19th centuries. We illustrate these uses using examples taken primarily from Brittany, and indicate their equivalents in other regions.

Fodder.- Because gorse is very high in proteins and nitrogen and is evergreen, it was an especially valuable fodder plant during the winter. It even improved the condition of horses (e.g. Desrez, 1842; Adrian, 1904) and the quantity and quality of milk from sheep and cows (e.g. Calvel, 1809). In France, the use of gorse as fodder was first recommended by a Breton agronomist in 1666 for horse breeding (Desrez, 1842), which was of prime economic importance before mechanization. Over the following centuries, many French publications extolled the qualities of gorse and described the techniques used to cultivate it (e.g. Calvel, 1809; Heuzé, 1856; Adrian, 1904). In its simplest form, gorse was grazed directly by animals in heathlands, but this was only suitable for goats and sheep. For horses and cattle, it was used as fodder in the stable or barn, and it either had to be harvested from the heathlands or hedges, or cultivated in real gorse fields (Calvel, 1809; Adrian, 1904). It was a key fodder crop which "*played a very considerable role in the rural economy*" in Brittany and other poor agricultural regions (Lucas, 1960; Sigout, 1999).

Fertilizer and animal bedding.- The use of gorse as animal bedding and fertilizer has been described since the 18th century (Tessier *et al.*, 1787; Calvel, 1809). Gorse was used to fertilize soil in different forms: as green fertilizer, inorganic fertilizer, or manure. On cultivated land, it could be grown between two rotations to enrich the soil with nitrogen (Antoine, 1999). After clearing a gorse field or heathland, gorse could be burned and its ashes made a good fertilizer. Through the cultivation of gorse fields, and their eventual burning, it was possible to reuse infertile soil to grow "*more interesting crops*" (Tessier *et al.*, 1787), such as cereals. Branches of gorse were used as the first layer of cattle bedding: it gave structure to the bedding and enriched it, and made it possible to save straw. Mixed with animal urine and faeces, it became a nutrient-rich manure used to fertilize fields.

Hedges and fences.- Because of its thorns, dense nature, and rapid growth, gorse forms impenetrable hedges. Planted on banks surrounding farmlands, it was used to fence in cattle, protect livestock and crops from the wind, and to keep intruders (human or animal) out (Calvel, 1809; Heuzé, 1856). Gorse was considered by some as "*the ultimate fence*" (Bixio, 1841). However, it seems that the use of gorse as quickset hedges was less widespread than its other uses in Brittany. When mentioned, hedging was not as well described as its use as fodder (e.g. Tessier *et al.*, 1787) and it was often criticized because gorse hedges frequently invaded neighbouring lands or tended to thin out at the bottom (e.g. Amoreux, 1787; Calvel, 1809; Bixio, 1841). The frequent reference to the ubiquity and size of gorse hedges in England implies a contrasting situation to that in France (e.g. Tessier *et al.*, 1787; Calvel, 1809).

Firewood.- As it burns fast and produces a lot of heat, gorse was a valuable source of fuel, especially in regions where wood was scarce, such as the windswept coasts of small islands. Gorse branches were harvested from hedges or heathland and incorporated into faggots made from various thorny plants (Darrot, 2005) for use as fuel in homes, bakers' ovens, lime kilns, or plaster kilns (e.g. Despommiers, 1770; Giraudon, 2007). Sometimes gorse was specifically sown for this purpose (Duhamel du Monceau, 1761).

Cultural heritage.- Gorse has a high patrimonial value; it is regarded by many as the emblematic plant of Brittany, and the gorse flower ("chorima" in Galician) is the national flower of Galicia. Gorse was an important part of the daily life of farmers; it was linked to certain superstitions and magical properties, and was cited in many tales, poems and songs (e.g. Lucas, 1960; Giraudon, 2007; Beaulieu & Pouëdras, 2014).

Gorse was thus regarded as a wealth, and had real economic importance: without being subject to a real business: it was possible to buy seeds from certain merchants (Calvel, 1809;

Miège, 1920); its cultivation and cutting were subject to regulations (Giraudon, 2007; Beaulieu & Pouëdras, 2014); and areas where gorse was damaged could become subject to claims (Adrian, 1904).

MANAGEMENT CONSTRAINTS AND DIFFICULTIES

The various uses of gorse required a certain set of skills and knowledge (described for example by Lucas, 1960 and Howkins, 1997, for the British Isles; and Beaulieu & Pouëdras, 2014 for Brittany). The main challenges posed by gorse lie in its thorny nature and its ability to spread quickly. Cutting gorse twigs required specific cutting tools and protective equipment for the body, hand, and legs, made out of goatskin or leather (Heuzé, 1856; Lucas, 1960; Beaulieu & Pouëdras, 2014).

Preparation of gorse for fodder – To use it as fodder, gorse had to be cut before full bloom and the increase in alkaloid levels, and then ground or 'bruised' to remove its thorns. Different grinding techniques were used depending on the region (Heuzé, 1856). Twigs were ground either with simple tools (between two stones or using a mallet and trough), by diverting the use of another type of mill (cider mills, water mills), or by building dedicated machines (at least after 1666; Desrez, 1842) (Fig. 2). These machines were constantly improved during the 19th century, and were the object of contests in fairs and articles in agronomic publications (e.g. Barral, 1861). Despite this, grinding was still very time consuming and was almost a full-time job for male farmers in the winter (Howkins, 1997; Beaulieu & Pouëdras, 2014).

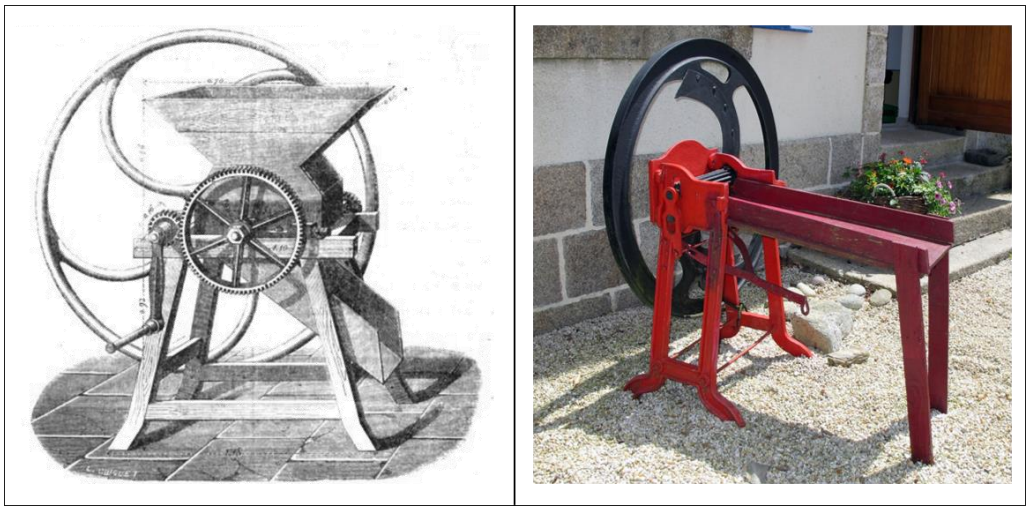

Figure 2.— Gorse grinder. Left, drawing from the 19th century (in Lecouteux, 1870); right, Museum Piece in the Ecomuseum of Traditions and Heritage "Skolig Al Louarn" in Plouvien, Brittany (photo Atlan, 2015).

How finely gorse was ground depended on the livestock: it had to be coarse for horses and sheep, but it had to be made into a good gruel for cattle (e.g. Loudon, 1826; Lecouteux 1893; Howkins, 1997). Because gruel quickly turned black in colour and became less appetizing to livestock, gorse had to be prepared daily, making its use as fodder even more challenging. These constraints limited the use of gorse outside Brittany, as noticed by the Mayor of a Breton municipality in 1840: "*I attempted to encourage the cultivation of this plant outside Brittany [...], the obligation to grind it, upsetting local customs, was met with opposition and unwillingness by the servants on the farms*" (De la Boëssière, 1840).

Expansion control.- As gorse grows quickly and produces large amounts of seeds, it can colonise abandoned areas very quickly. In particular, when used as a hedge, it is necessary to ensure strict management so that it does not spread into neighbouring fields. In some regions of France where gorse was introduced in the 19th century, its tendency to invade farmland led to the avoidance of its use as hedges (Crévélier, 1896).

We have not found any written records of the methods used by Breton farmers in the 19th century to limit this undesirable spread, but our surveys in Brittany show that farmers are well aware that if gorse in hedges or heathland is not managed, it will spread. They use routine and well-established practices, adapted from those inherited from the pre-modernization period and learnt from fathers and/or grand-fathers: they trim the hedges at regular time intervals, and mow meadows (every year) and heathlands (every 2-5 years). In terrains that are more difficult to access, the frequency and method of trimming is adapted to the terrain: for example, they could be trimmed using a brushcutter (approximately every 4 years) or a chainsaw (every 6-7 years).

Due to these uses and management constraints, gorse acquired an ambivalent status: it was both useful, and a symbol of a certain wildness that needed to be controlled. It was not cultivated in fertile soil where other crops could grow, given that it required tedious preparation and was difficult to remove completely from a field (e.g. Clément; 1856). In these soils, it was considered as a weed that had to be eradicted (e.g. Despommiers, 1770; Clément, 1856). In the rest of Europe, gorse was associated with infertile soil and its value or perception depended on the context. For example in England, it "*deserved to be encouraged and propagated*" in the wild and in pastures, but "*ought to be completely eradicated as a nuisance*" in arable and fertile soil (Walker, 1808).

INTRODUCTION OF GORSE TO THE EUROPEAN COLONIES

Gorse was a valuable ally for European settlers, given its multiple uses, its ability to grow in poor soil, and its deep roots in the traditions and culture of Western Europe. Most introductions outside Europe took place during the 19th century in the colonies (Fig. 3). The introduction dates are known for many countries, but it is more difficult to retrace the motives behind the introduction of gorse and its actual usage in the introduced areas.

MOTIVATIONS FOR THE INTRODUCTION AND USE IN REUNION ISLAND

Gorse is rarely mentioned in the digitized volumes of the French *Maritime and Colonial Annals* (more than 40 volumes covering the years 1809 to 1847). Despite this, several elements taken together suggest that animal feed was one of main reasons for its export from France. In the official General Customs Tariff documents (1844, 1857, 1870), gorse seeds were classified in the fodder category, and then under the "*grassland seeds*" section, like clover or alfalfa. Exports to the French colonies could have also been motivated by its use as firewood, fencing (for example, on Saint Pierre and Miquelon; Bajot, 1832), or fertilizer (Chevalier, 1941). In Reunion Island, it was described as being introduced for "*economic purposes*" in 1825 (Bréon, 1825) and as widespread in the main agricultural high plain (La Plaine des Cafres) in 1895 (Jacob de Cordemoy, 1895). Agricultural uses of this period are mentioned in recent documents (e.g. Lavergne, 1980 for fodder, Carayol, 1984 for hedges), but not in period documents. The precise motives for its introduction and its initial uses were retraced by cross-checking documentary research and semi-structured interviews.

Animal feed.- Many of the stock farmers who were interviewed in the agricultural high plains of "La Plaine des Cafres", where gorse is still currently found, recalled their parents or grandparents talking about gorse as a source of food for animals: "*The donkeys were fond of it"*, "*food for sheep"*, "*it was introduced for the goats*". However, the need to grind gorse or the existence of a grinder was mentioned only in one document (Hanens, 1937), suggesting that gorse was not commonly used as prepared fodder, as in the native areas. In fact, although people still remember that it was introduced as a food source, its actual use has been limited to direct grazing,

mainly for sheep, the principal animal raised on the plain during the first half of the 20th century, and sometimes for goats. Gorse is considered as unsuitable food for cattle: "*Our own cows, they don't eat that*".

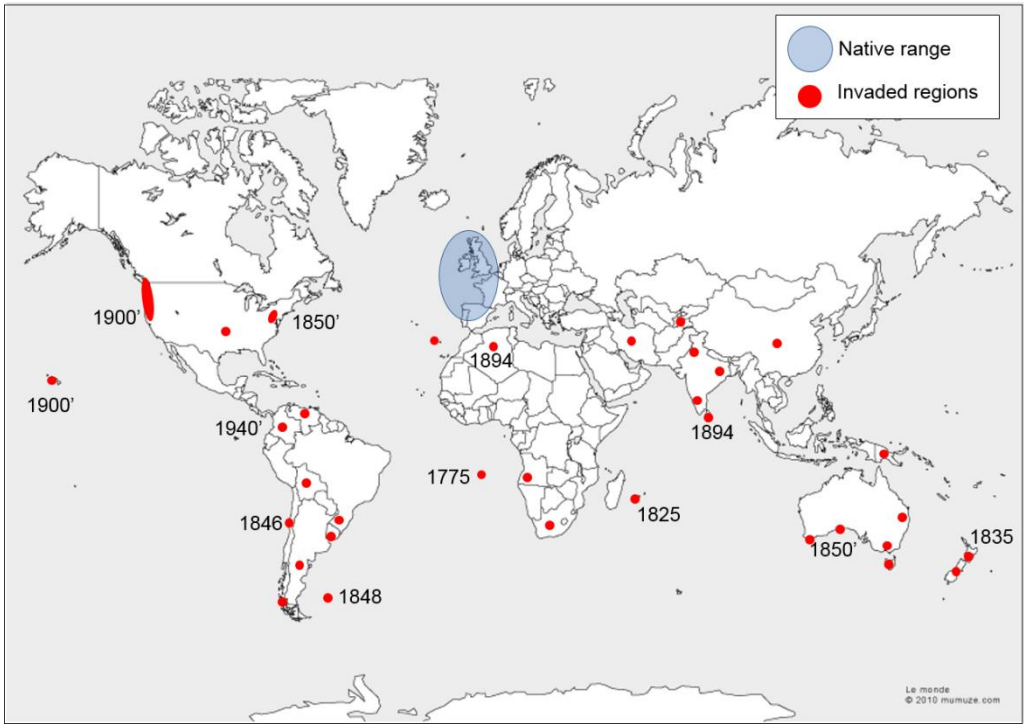

Figure 3.— Gorse distribution (not exhaustive) with the main localities and dates of first introduction (Forster, 1777; Bréon, 1825; Darwin, 1839; Gay, 1846; Dawson, 1890; Debeaux, 1894; Trimen, 1894; Low, 1986; Mack, 1991; Markin *et al.*, 1996; Parsons & Cuthbertson, 2001; Leon & Vargas Rios, 2009; Hornoy, 2012).

*Hedges and fence**s***.- Another use frequently mentioned by the survey respondents was the use of gorse to create quickset hedges or protective fences, notably "*to prevent people from entering the farm, [...]or the fields*" or "*to keep animals from getting out and grazing in the common areas*". This corresponds to the regulatory environment in the mid-19th century. In 1851, when concessions were granted for La Plaine des Cafres, the farmers had to fence their land otherwise it would be reassigned (Textor de Ravisi, 1852). However, Reunion Island does not have any indigenous or endemic thorny plants that can be used as protective fences and gorse was one of the rare introduced plant species able to fill this role effectively.

Aesthetics and nostalgia.- Among the authors giving their views as to why gorse was introduced to Reunion Island, some authors (Benda, 1956; Vailland, 1964; Lavergne 1980) said that it was for aesthetic and emotional reasons (nostalgia for the homeland): "*It is said that it was introduced by a Breton priest trying to evoke his native land.*"; "*A Breton settler who was nostalgic for his native land had some gorse seedlings brought here which he planted in front of his door.*" The motivations relating to agricultural or emotional reasons given by the survey responders, are not contradictory. Responders who mentioned both aspects almost always ended by emphasizing the aesthetics of the plant: *"gorse was introduced because, after all, it was pretty*" [a farmer of La Plaine des Cafres].

MOTIVES FOR THE INTRODUCTION AND USE OF GORSE IN OTHER REGIONS

The three major motives (hedges, animal feed, and aesthetics) behind the introduction of gorse to Reunion Island were found in varying degrees throughout the whole of the introduced range. Use as hedges or fences was found most frequently in documents that mention why gorse was introduced. This was the case in Australia (Ewart & Tovey, 1909), New Zealand (Darwin, 1839; Hargreaves, 1965), the Falklands (Dallimore, 1919), Colombia (Leon & Vargas Rios, 2009), and Chile (Norambuena *et al.* 2000), and possibly also in Java (Backer, 1963) and Argentina (Manganaro, 1919). Gorse was used to make quick and cheap fences, especially in regions where wood and stone were rare (Bagge, 2014), and this use was initially encouraged in New Zealand and Australia, where gorse was distributed and sold (e.g. Lee *et al.*, 1986; Myers & Bazely, 2003; Isern, 2007). In sales advertisements of the 1840s in New Zealand, it was sometimes classified amongst fodder, and sometimes as a hedge plant (e.g. *New Zealander*, 10 January 1846 p. 1; *Wellington Independent*, 5 July 1851, p. 2). In other countries, the introduction of gorse as fodder is also mentioned, for example in Chile (Norambuena *et al.* 2000), Australia (Parsons & Cuthbertson, 2001) and New Zealand (Thomson, 1922).

Besides agricultural uses, gorse was used to respond to other local issues, such as setting property boundaries within cities in New Zealand (Myers & Bazely, 2003), enclosing the lands of the Chisaca water reservoir in the 1840s in Colombia (Leon & Vargas Rios, 2009), camouflaging and protecting military installations in the USA (Bingelli, 2001), or stabilizing coastal dunes in Chile (FAO, 2011). Aesthetics or nostalgia also motivated gorse introduction in the USA (Hill, 1955; Mack, 1991), Tierra del Fuego (Moore, 1983), and the Bermudas (Britton, 1918). Overall, the motives and the actual uses of gorse depended both on the local needs of the receiving country (which changed over time, and varied in different socio-economic contexts), and on the practices and knowledge passed on from the country of origin. In some countries, voluntary introduction could have been supplemented with unintentional introductions. This was the case on the island of Tenerife (Canary Islands) where gorse has been naturalized since at least 1803 (Bory de Saint-Vincent in 1803; Smith *et al*., 2002) and where the seeds were also inadvertently introduced in the middle of 20th century as part of pine plantation program (Kundel, 1976; Sanz Elorza *et al*., 2004).

A PARTIAL TRANSFER OF KNOWLEDGE AND PRACTICES

Although the reasons for importing gorse into the colonies echoed the agricultural uses at the same time in Europe, it seems that some of the knowledge and practices were not passed on to the introduced regions, and that its capacity to invade pastures and open areas was poorly anticipated.

Why was use of gorse so marginal for fodder in introduced regions? Our first hypothesis is that knowledge relating to how to prepare gorse for fodder was not always transferred. Agronomists who encouraged the export of gorse to the colonies as fodder emphasised its protein content, its low cost, and its ability to grow on poor soils. They sometimes described the cultivation methods (sowing, terrain, trimming), but they rarely described the time and method needed to grind gorse. When these methods were mentioned, it was only briefly. In Reunion Island, current farmers are not aware that gorse needs to be ground before it can be given to livestock, particularly cattle. In New Zealand, the need to grind gorse was mentioned in some texts, but the way to prepare the fodder depending on the type of animal for which the feed was intended was not dealt with. Our second – not exclusive - hypothesis is that the use of gorse as fodder was incompatible with the way farms were organized and structured in the colonies. Furthermore, in Reunion Island and in New Zealand, the main type of livestock farming practiced from the 19th century to the 1970s was extensive free-range farming, both for cattle and sheep. This practice is not compatible with the technical preparation of fodder that requires a high amount of labour and has to be given daily in stable and barns.

Traditional knowledge about how to control gorse expansion (mowing, regular trimming and ploughing), does not seem to have been transferred. We did not find any mention of these practices in any of the period documents, either in France or in the other native regions of gorse. Agronomists who encouraged the use of gorse and its export did not mention that gorse thickets and hedges had to be maintained to prevent gorse spread. They did not even warn that gorse might escape from the hedgerows and invade fields. Thus, most of the farmers' practical know-how was not passed on. This knowledge could have been transferred orally if the farmers in the introduced areas had come from farms in the native region, but in Reunion Island at least, this was not the case. Farmers who founded the high plains farms had been in Reunion Island for several generations (e.g. Lavaux, 1998). We do not have similar information regarding other invaded countries, but it is likely that this is also true in many colonies. The lands where gorse grows have poor soils, and are in elevated regions in the tropics. Therefore, they are not the type of lands that were cultivated by the first settlers.

EVOLUTION OF THE MANAGEMENT OF GORSE IN NATIVE AND INVADED REGIONS

The transformation of a peasant agricultural model towards modern agriculture took place throughout Europe at about the same time, but the trajectories followed and the resulting situations were somewhat different, depending on the countries. Therefore in this section, we focus exclusively on the two French regions, Brittany and Reunion Island.

ABANDONMENT OF TRADITIONAL USES IN BRITTANY

After the Second World War, the peasant farming model in which gorse had its rightful place no longer corresponded to the needs of the period: France and Europe needed to rebuild themselves. Agriculture contributed to this in two ways: firstly by providing a large workforce to secondary and tertiary sectors, leading to a rural exodus (Pisani, 2004); and secondly by becoming major consumers of industrial products (fuel, fertilizers and treatments, seeds, and building materials) and exporting much higher volumes of food (Mendras, 1967; Hervieu & Purseigle, 2013). Thus, self-produced fodder, fertilizer and fuel using local natural resources gave way to inputs manufactured outside the region. Hedges were destroyed and levelled in order to open up large plots that could be worked with machines (Périchon, 2004), fences were replaced by barbed-wire or electric fences, and draft horses were permanently replaced by tractors. Carried away by these changes, gorse was no longer used for any agricultural purpose on farms and only its negative properties (see above) remained, despite the recognition of its aesthetic and cultural values *"Gorse, it's pretty but it's a pain in the neck"*, summed up a Breton farmer in 2009. Gorse was confined to residual hedgerows and became a specific marker for uncultivated regions: heathland and abandoned fields. *"We set this plot aside as fallow land: after two or three years, it was full of gorse again! Gorse has a hard life!*" [a Breton farmer, 2005, in Darrot (2005)], *"Look at that, they put gorse in the replanted hedge. As if we needed gorse! Gorse is prickly, it's useless. We have electric fences for that!*" [A Breton farmer, 2015]. As far as the farmers were concerned, gorse was unwelcome.

CRITICISM OF THIS MODERNIZATION AND OPENING UP OF INNOVATION SPACE

In a movement that started in the 1970s, and then considerably intensified in the years 1990-2000, environmental concerns, raised mostly by non-agricultural stakeholders shook the foundations of French agriculture (Mathieu & Jolivet, 1989; Billaud, 2009). The side effects of the modernized model and their public cost in terms of negative environmental consequences (Mollard *et al.*, 2014) were transferred to the public stage: water pollution, animal welfare, food scandals, etc. This context of criticism instigated reactions by sections of the agricultural world: the range of technical models was gradually expanded, and innovative practices based on the idea of "sustainability" began to emerge (Deléage, 2005; Hervieu & Purseigle, 2013). In this context, new

societal debates emerged on how to preserve natural resources in rural areas. The declaration of areas designated as protected sites due to their high natural value gradually became more structured and more common (e.g. Natura 2000 areas, national and regional parks, coastline conservation; Aubertin *et al*., 2006).

Today, rural areas appear as a mosaic, made up of areas of intensive agriculture, areas of agriculture said to be more "sustainable", and protected natural areas, where farming activity is either tolerated (with constraints) or not, depending on the situation. In this modern ensemble, gorse is managed in a variety of ways. In protected natural spaces, gorse is maintained. In some places, it is managed to evoke the heathland landscapes of the 19th century where it was exploited as a sub-spontaneous natural resource by farmers (Symel, 2008; Jarnoux, 2008). This is done by clearcutting heathland using mechanical methods and/or controlled grazing. In other places, especially on the coast, it is fully developed over large areas where the landscape is marked by the presence of this patrimonial plant.

In agricultural areas that are intensively and conventionally managed, gorse is still not welcome, except in some hedgerows, where it is closely controlled. On the other hand, farmers who have heavily invested in alternative practices might once again be interested in gorse, as a free local natural resource. Similarly, gorse might have a useful economic value in natural protected areas managed by public institutions or by farmers working in cooperation with these institutions. Local experiments are being carried out on how to incorporate gorse into dry greenfuels for wood-fired burners, into animal feed as dehydrated pellets, and into farm or industrial compost. However, these techniques must evolve significantly in order to make them profitable. Until now, this scenario has not been possible due to several combined factors. Firstly, in comparison with the past, farms today have fewer workers per hectare: at present, the amount of time and work needed to prepare gorse as fodder instead of commercially available feed pellets is still too demanding (Darrot & Beuret, 2010). Secondly, the advisory and research system that produces and disseminates technical references is still dominated by the heteronomous model, in which production is dependent on upstream and downstream activities, and is not very open to this type of development. Thirdly, and resulting from the second point, there are no major industries or machinery for the production and valorization of gorse. The land on which gorse grows is often rocky and may have a steep relief. Although some farmers have developed or even created equipment suitable for these conditions, these useful experiments are only seldom heard of today, partly because they fall within solutions that have been "cobbled together" depending on the local needs.

The situation is different for public managers of natural areas. As long as they are not required to earn income from their products, they are given some leeway to perform experiments. In these areas it is now possible to observe interesting experimental situations, and technical references are being produced that may interest future managers as well as farmers. In this way, the Association of Local Initiatives in the field of Energy and Environment (AILE), financed by the public Agency for the Environment and Energy Management (ADEME), produced references on the heat capacity of fuels made from heathland wood, including gorse. The Regional Natural Park of Armorique and the General Council of the Ille-et-Vilaine department are carrying out experiments in the transformation of gorse heathland into pasture. The experiments carried out at the Nivot agricultural secondary school on making compost piles out of material cut from heathland should also be mentioned.

MANAGEMENT IN REUNION ISLAND AND OTHER INVADED COUNTRIES

It is possible to gain insight into areas invaded by gorse in Reunion Island using the same principle of spatial partitioning: agricultural regions on the one hand, and protected natural regions that are publicly managed, on the other hand. In agricultural regions affected by gorse, i.e. cattle rearing regions in the high plains, there are two categories of situations: (i) the workforce, level of

mechanization and animal density are high enough to maintain significant grazing pressure, confining gorse to the edges of fields, hedges, or abandoned areas, where it is controlled annually using mechanical or chemical means; (ii) grazing pressure is too low and gorse quickly takes over the pastures, rendering them impassable, which entails the mobilization of considerable resources to recover them. The latter situation is particularly seen when there is a small workforce on the agricultural holding. It is also seen in hard-to-access areas where it is difficult, and sometimes impossible, to carry out mechanical interventions.

Two situations can also be distinguished in natural areas, depending on the importance of the biodiversity concerns. In natural areas without specific biodiversity challenges (which is rare on Reunion Island), it could be possible to transfer Breton management experiments using innovative techniques conducted in protected natural areas, or on sustainable farms: the use of a roller chopper followed by treading on pastures, the use of a motorized and innovative gorse grinder for fodder, etc. However, on Reunion Island, most natural areas having major biodiversity issues are protected areas under public management (Atlan & Darrot, 2012). When gorse has a strong presence, it becomes embedded within a plant mosaic consisting of native and protected species; in this case, mechanized grinding techniques could not be used as they would damage the neighbouring flora. Although gorse is cut by hand, in combination with targeted chemical treatments, the magnitude of the task seems overwhelming, giving the impression of *"the Danaïds' jars" or "the myth of Sisyphus"* [managers, 2010]. Institutions on Reunion Island are still searching for solutions.

This spatialization of management problems is not specific to Reunion Island. In their analysis on a wide range of invaded regions (including Australia, New Zealand, the USA and Chili), Hill *et al.* (2008) proposed the same typology between productive regions, in which the classical mechanical and chemical methods are able to contain gorse, and *"lands that provide low economic return, land that is managed for biodiversity value"* in which the same methods fail to control gorse. In many of these countries (but not in Réunion Island), biological control agents have been introduced. When combined with mechanical and chemical techniques, they helped to reduce the spread of gorse, but their efficiency remained limited.

CONCLUSION AND PERSPECTIVES

By retracing the historical evolution of the uses of gorse in native and invaded regions, we were able to understand why this plant was introduced, sometimes on a large scale, in so many parts of the world and we identified the factors explaining why its introduction has often resulted in an uncontrolled geographical expansion.

The main qualities of gorse are its ability to grow on poor soils, and its physical and chemical properties (e.g. thorns, protein, nitrogen), which led people to use it for multiple purposes. However, transposition was far from straightforward between native and introduced regions and the predominant uses were not identical across regions. This is partly due to different needs, different socio-economic, socio-cultural and geographical situations, but also to the non-transfer of practices for usage and control techniques to prevent expansion. These elements, combined with biological features such as the evolution of gorse toward faster growth and competitive ability, help explain why this species, which does not pose a problem in its native region, has become a major invasive species in both agricultural and natural areas in many countries.

Nowadays, certain problems due to the expansion of gorse in invaded regions might be solved by using the machines created in Brittany for the management of heathland, the rehabilitation of abandoned fields, or to control the spread of gorse. The use of gorse as industrial or farm compost fits well with these maintenance methods. This raises the question of the potential economic development of gorse based on modern adaptations of the ancient uses (fuel, fertiliser, fodder), as

soon as large volumes are available and mechanic harvesting is possible. In agricultural areas, the development of gorse as an agricultural product could constitute a real incentive for its management. It could be introduced as sustainable development, on the one hand by reducing the use of herbicides, and creating an economic resource and jobs, and on the other hand, as an approach to regional autonomy, which is fundamental in times of global changes. However, several points need to be improved and prior knowledge of technical information is essential: yield, detailed fodder values, economic advantages compared with other dietary supplements (including soybeans), number of working hours required, etc. In natural areas, the economic development of gorse products could potentially reduce management costs and facilitate the sustainability of the initiatives. However, the difficulty of using machines and undertaking large-scale actions in protected natural areas limits the possibilities of harvesting it.

In invaded countries, considering gorse as useful or even economically profitable also poses a political problem. For environmental stakeholders who focus on the conservation of native species, the economic development of an invasive species could actually have a converse effect to that intended: the creation of a commercial sector, plantations, increased risk of spreading and the beginning of controversies (Nuñez *et al*., 2012). In the regulation adopted by the European Union on 29 September 2014, it is stipulated that Invasive Alien Species shall not be intentionally placed on the market, used or exchanged. Although these provisions may be amended, they do not create a favourable environment for the implementation of management methods that integrate the valuation of gorse. However, the risk may depend on the species and could possibly be prevented by appropriate measures. The factors that encourage or hinder the integration of traditional uses of gorse into management techniques are likely to evolve over time. In any case, this study shows that a better knowledge of the motivations and practices that led to the introduction of a species that has since become invasive, could help to expand the potential fields of management innovations.

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